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PHILCO CORPORATION
LANSDALE DIVISION
Lansdale, Pennsylvania

PEM for

ELECTROCHEMICAL ETCHED TRANSISTORS

Final Progress Report

Period Covered:
19 May 1961 to 19 May 1963

Order No. 6014-PP-61-81-81

Contract No. DA-36-039-SC-85959

Object of Study:

Production Engineering Measure (PEM) in accordance with Step I of Signal Corps Industrial Preparedness Procurement Requirement (SCIPPR) No. 15 dated 1 October 1958, for specific processes applicable to the Electrochemical Etched Transistors.

R-230.1

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SECTION I - ABSTRACT

The report reviews the work done on Contract No. DA-36-039-SC-85959. A brief introduction giving background which influenced implementation of the program is followed by discussions of design considerations and specific problems encountered during fabrication and check-out of the prototype machine. Difficulties in the areas of machine layout to accommodate the several major subassemblies are described and the methods of obtaining the required accurate positioning of transistor blank and whiskers are discussed.

Some of the characteristics of the machine are listed, and a functional description is given of the over-all machine operating cycle and of the whisker plating and soldering steps.

Production capability of the machine has been evaluated at 2680 actual starts per shift (machine cycle time indicates 3200 starts possible). Final test yield to the applicable specification was 36%; however, 90% of the gross input to final test represented salable transistors in the family covered by the specification.

SECTION II - PURPOSE

The purpose of this contract is to design, construct, and prove-in semi-automatic production equipment for lead preparation and attachment to silicon dice. The equipment shall be limited to one prototype machine capable of producing parts directed toward a rate of at least 600 transistors meeting the applicable specifications per eight-hour day.

The contractor shall be required, upon completion of the production equipment, to integrate this equipment into a current production line manufacturing the specified devices. The acceptability of the equipment will be demonstrated by the submission of data taken on units produced using this equipment.

SECTION III - NARRATIVE AND DATA

INTRODUCTION

Background

Inconsistencies in SAT units produced by the conventional process of manual whisker attachment, and the desire to attain a higher production rate were basic reasons for implementing the subject Production Engineering Measure with the objective of designing a Semi-automatic Whisker Attacher and building a prototype machine capable of a production rate of 600 transistors meeting applicable specifications per eight-hour day.

In the manual whisker attachment process, an operator inserts the processed carrier-mounted transistor into a soldering fixture, manually loads the previously-plated whisker wires into jaws of the process jig, advances the whisker wires and locates them so that contact is made by each with the center of its associated transistor electrode. The operator then applies flux to the assembly and turns on radiant heat. After the solder has fused with the aluminum electrodes, the operator turns off the heat, allows adequate cooling time, and removes the transistor carrier. The cycle is repeated with each transistor. An experienced operator produces about 100 units per hour with a 95% mechanical yield using this manual process.

The manual whisker attachment process is operator dependent and therefore subject to considerable quality variation from one unit to the next. For instance, if a whisker wire is clamped at a different length, the change in heat sink effect varies the heating pattern and the solder results. Also, the location of the whisker wires with respect to electrode centers should be reproduced within 0.0002", a margin which is not consistently maintained by operators. The amounts of applied flux and the length of soldering time are additional factors that vary considerably in the manual process and cause inconsistent results in device manufacture.

Program Schedule

The contract initially called for completion of the prototype machine by February 20, 1963. A revision extended the contract to May 20, 1963. (Re Modification No. 2, 18 June 1962.) The extension provided time for investigation of a resistance soldering method as an optional feature.

Manufacture of the machine was begun five months after the effective date of the contract. Machine manufacture, including all assembly work and initial debugging, was completed by the end of the seventeenth month.

Installation of the machine in the factory production area was accomplished by mid-October 1962, and the visual inspection was held on November 20, 1962. The scheduled run-in of five months was extended to six months, largely because it was felt that the number of units to be run for acceptance data ought to be limited to obtain a better cross-section of the machine capability over an extended time period.

DESIGN CONSIDERATIONS AND MACHINE CONSTRUCTION DIFFICULTIES

General

The prototype Semi-automatic Whisker Attacher built on this contract performs automatically all the steps of the manual whisker attachment process (see Background in the Introduction to this section), except that an operator must insert each carrier-mounted transistor and remove it after whisker attachment is completed. Several variations in layout of mechanisms for specific process steps were considered in arriving at the final machine design. The major design considerations, the problems encountered in machine construction and their solutions are discussed in the following paragraphs.

Simultaneous Attachment of Collector and Emitter Whiskers

The decision to design the machine to solder both whiskers simultaneously, instead of in two successive operations, was based on experience in silicon transistor production. The thermal conductivity of silicon is high enough to cause shifting of the first whisker soldered when the heat is applied for soldering of the second whisker. This problem is aggravated by the high thermal conductivity of the aluminum transistor electrodes. The decision to have the machine attach the two whiskers simultaneously introduced problems of space allotments for various machine subassemblies.

Space Allotments for Machine Subassemblies

Combining the two whisker attachers into one compact unit presented a problem in view of the several machine subassemblies needed to accomplish the steps of whisker preparation and attachment. Typical of the space limitations involved was the need to mount one set of heating elements and one blank optics assembly at the center of the two whisker attacher assemblies, each of which would be required to advance and attach a short whisker in the presence of hydrogen jet, heater elements, and the blank optics assembly. Furthermore, a transistor carrier fixture with X- and Y-positioning servos would be required, with a location near the center of the machine. Finally, space allocations were necessary for two more optics systems with associated servos for X- and Y-orientation of the whisker wires.

Initial Layout

Initially it was decided to mount the wire feed, plating tank, whisker grip and transfer assembly, and whisker cut and forming assembly on the whisker positioning plate. This design was to have all assemblies operating on the whisker moving as a unit, thereby maintaining constant position relationships. Adjustment of a servo would be accompanied by simultaneous movement of grip jaws and related movements of other assemblies, maintaining the positional relationships essential for consistent results in whisker attachment. When detailed layouts were made for some of the assemblies, it became apparent that the mass of the whisker positioning plate would need to be very large to mount the several assemblies to be carried. Another approach was studied.

Final Layout

In the layout which was selected for machine fabrication, only the whisker grip and transfer assembly was mounted on the whisker positioning servo plate, permitting the plate to be much smaller and lighter than that called for by the initial layout. The other assemblies were mounted to the base machine. With the selected configuration, it was necessary for the whisker grip and transfer assembly to recenter to some desired position for pickup of the new whisker after positioning the preceding whisker. In making the detailed layouts, the necessary recentering was shown to be feasible by use of a lightweight spring-loaded slide, operating through a modified ball pivot system. In the "back" position of the slide, the radius between the ball joint and the whisker grip jaws is reduced nearly to zero, whereas at the "in" position, the radius is large, allowing for whisker positioning with the ball joints as the pivot.

In the final layout, the electrode centering optics system and the heaters were slide mounted and moved in and out in the desired sequence. This arrangement eased the problem of space availability for all necessary assemblies to be included at the center of the machine. The optics of the electrode centering servo system were designed with 16X magnification. This proved to be a problem, observed in initial fabrication and testing of the mechanism. Slight motions, magnified 16X, created large position errors. The assembly was built with a cam-driven ball slide and a fixed stop. The stop created an amount of shock which, due to magnification of the optics, resulted in error. The difficulty was eliminated by installation of a dash pot.

A problem with shock was also encountered in connection with the stop used for the grip and transfer slide (which moves the whisker wire from cutting and forming to the bonding position). Two air cylinders were incorporated as dash pots, causing the slide to approach the stop without shock.

Synchronous Operation

Synchronous operation of machine motions was obtained by choice of cam drives with drive power from a 220-volt 3-phase induction motor with integral brake. Space and cost considerations, as well as the low inertia of the selected brake-motor system, affected the choice. The motor drives two worm shafts, each of which drives a worm gear mounted to an associated cam shaft (Figure 1). Cam drive of the machine motions was selected for consistency and reproducibility.

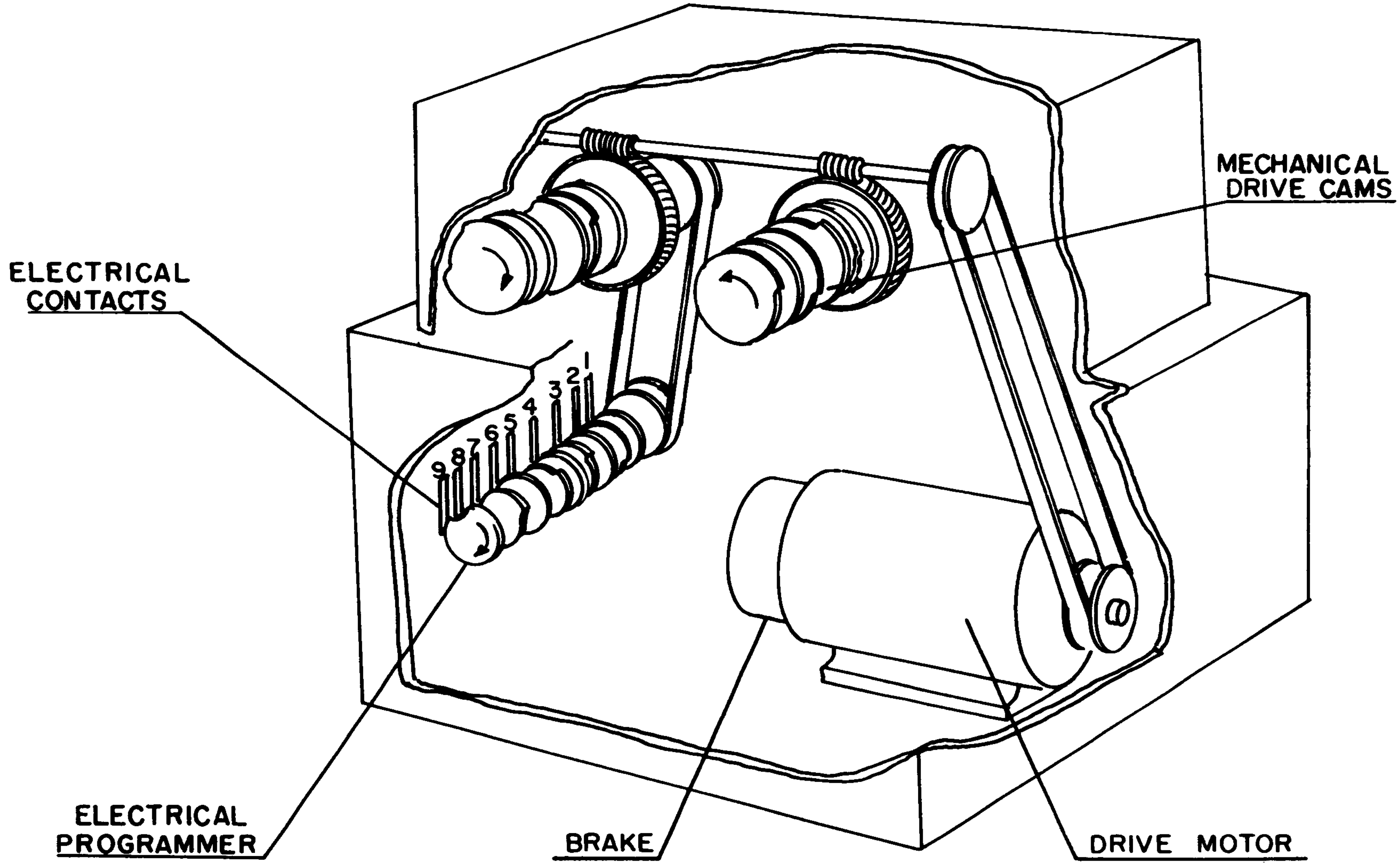

Figure 1. Machine Drive System. Artist's Conception.

Transistor Electrode Positioning

Obtaining an error signal for servo positioning of the carrier-mounted transistor presented some difficulty and several methods were investigated. The difficulty in obtaining a suitable error signal is chiefly because:

1. Illumination is critical,
2. The required position of the lens system causes interference with soldering, and therefore the lens system must be moved in and out,
3. The optical path cannot be straight and the system elements must be small,
4. The available error signals are small and need to be greatly amplified.

The following error signal generating systems were investigated:

1. Fiber optics for beam splitting. In this system, a fiber bundle would receive the image at one end and divide it into four quadrants at the other end. A photosensor associated with each quadrant would pick up and transmit the signal to amplifiers.

2. One sensor divided into four quadrants. In this system, a solar cell and phototransistor were divided into four quadrants. The dividing lines were very small. By suitable magnification of the transistor electrode, the dividing lines could be considered negligible.

3. One lens system with a half-silvered mirror for splitting of the beam, using half of the beam for X-positioning and the other half for Y-positioning. The divided light beams were fed through a chopper system to photomultipliers, selected for their superior sensitivity.

The first two systems enumerated above were d-c systems. They presented problems in stability and sensitivity and were not consistent in operation. Also, the fiber optics system is very expensive. The third system is an a-c system. It presented no problem of stability and provided consistent results. It is the system used in the prototype machine.

Whisker Servo System

From the time of initial machine concept, two optical systems 90° apart were considered. The desire was to servo both whiskers simultaneously to keep machine cycle time to a minimum. Space could also be conserved if each whisker would not require individual X and Y optics systems. The whiskers were close enough that a single lens system could transmit the images through separate slits to two photosensitive elements within one chopper system. The arrangement was feasible but a problem was encountered in using a phototube with two elements. Internal reflections within the tube envelope caused cross-coupling of signals and resulted in improper positioning. The use of two separate small phototubes inside the chopper wheel resolved this difficulty.

Among other systems considered for whisker wire servoing, but found impractical, were a system of mechanically shuttering the image and using one phototube to receive the information. The indication was that the system lacked reliability; furthermore, it would require too much machine time.

Resistance Soldering Technique

Different methods of whisker attachment were considered and some investigation of methods was conducted during the course of the contract. An aim of part of the investigations was to eliminate the need for special preparation of the transistor electrodes. Different reducing atmospheres were used during the heating cycle but no favorable results were obtained. Trials of a resistance soldering technique indicated feasibility of obtaining good whisker attachment without the conventional preparation of electrodes. In this technique, current was passed through the preheated transistor, causing the solder to fuse with the electrode. A resistance soldering system was added to the machine as an optional soldering technique. Evaluation of the system in the machine yielded results lacking in the consistent high quality level necessary to recommend full production use in the machine. Further investigation would be necessary to completely define the problems involved.

MACHINE CHARACTERISTICS AND FUNCTIONAL DESCRIPTION

Characteristics

The Semi-automatic Whisker Attacher has the following characteristics:

1. The over-all dimensions of the assembly are 36" (width), 28" (depth), and 96" (height).
2. Weight - approximately 1200 pounds.
3. Cycle time, from insertion of carrier-mounted

transistor to removal of the carrier, approximately 8.0 seconds.

4. Accuracy of positioning of whiskers is ±0.1 mil of center of electrode.

5. Anticipated mechanical yield is 95%, with an 80% utilization factor.

Figure 2 is an over-all view of the prototype machine.

Functional Description

The basic elements involved in the automatic whisker attaching operation are shown in Figure 3. Although the operation is continuous from start to finish, it is convenient to show operation in two phases: (1) plating, bending and cutting; and (2) alignment and bonding. The steps included in the first phase are illustrated in Figure 4; the steps in the second phase are shown in Figure 5.

Summary of Over-all Operating Cycle:

During normal operation of the whisker attacher, plating of a pair of whiskers and bonding of the previously prepared whiskers are initiated simultaneously. Assuming normal operation, the operating sequence is as follows. After attachment of a

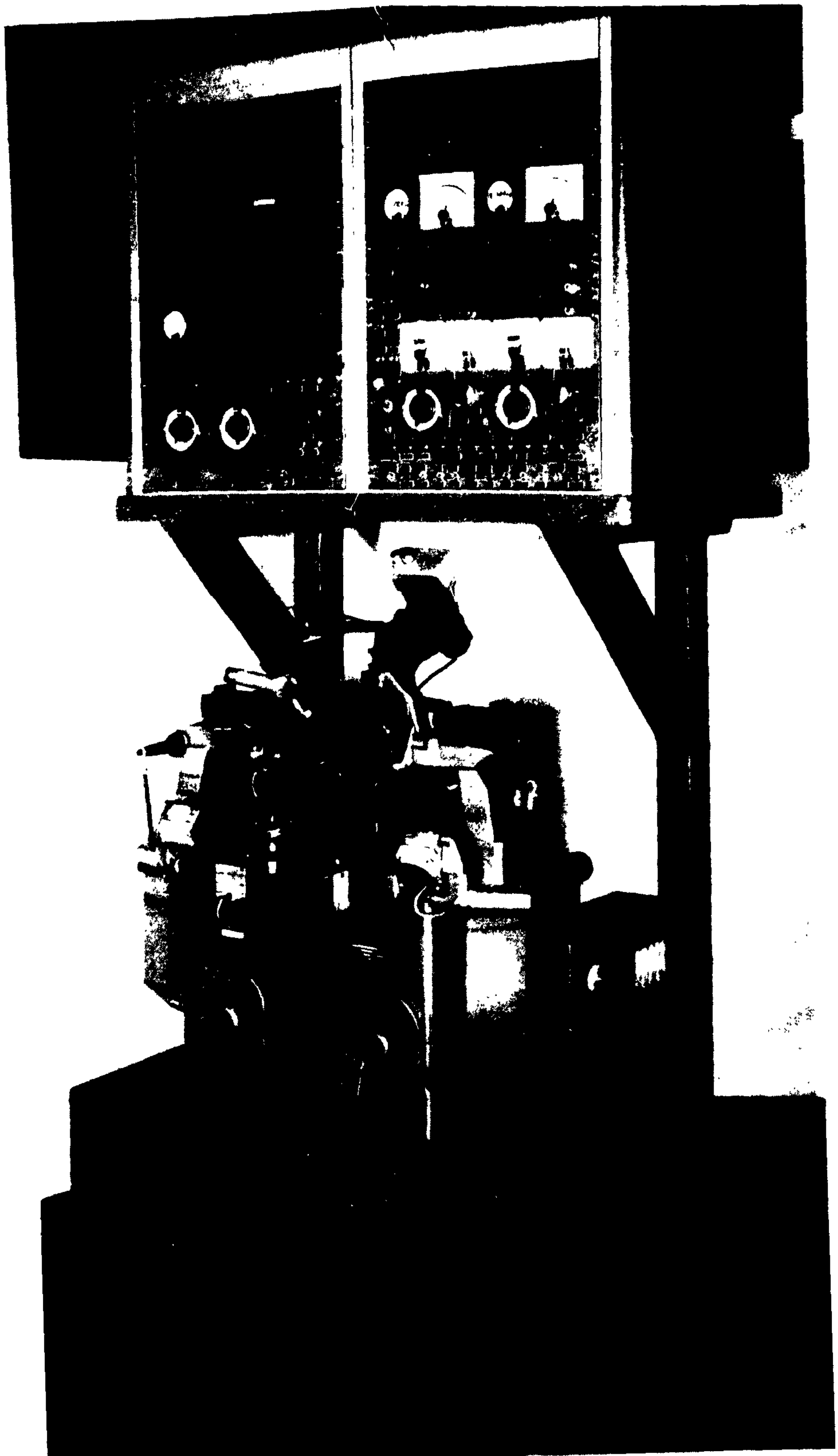

Figure 2. Semi-automatic Whisker Attacher

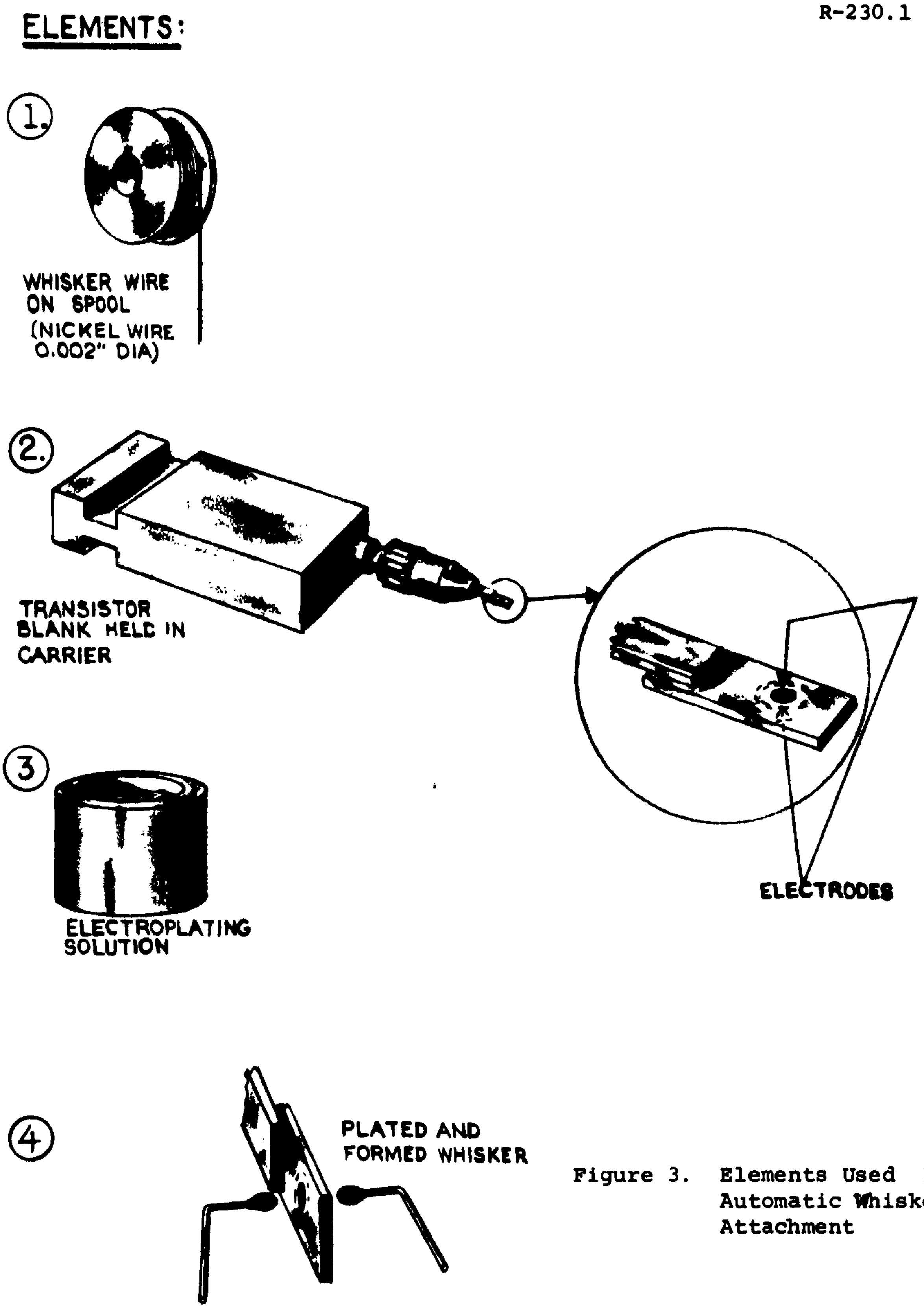

Figure 3. Elements Used In Automatic Whisker Attachment

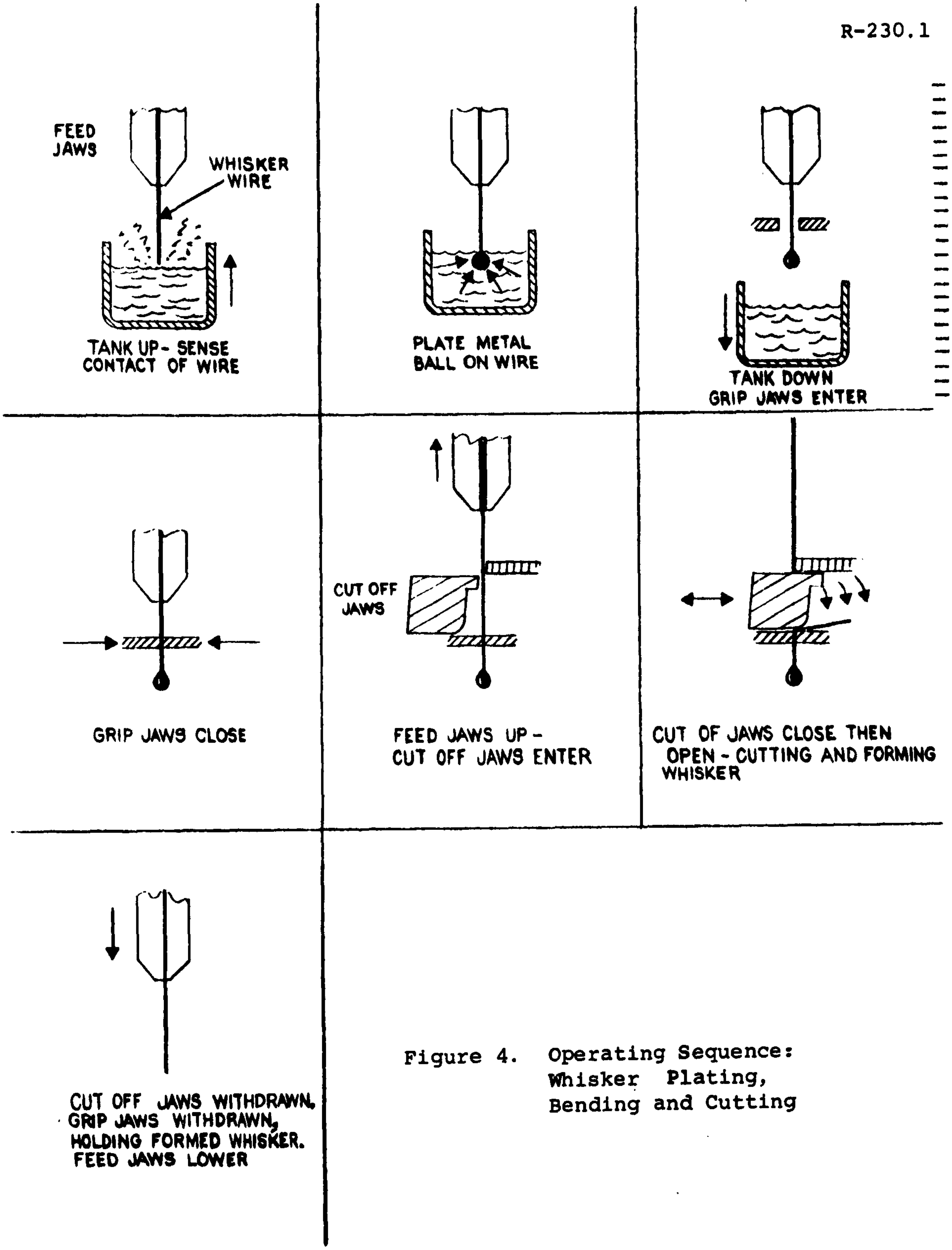

Figure 4. Operating Sequence: Whisker Plating, Bending and Cutting

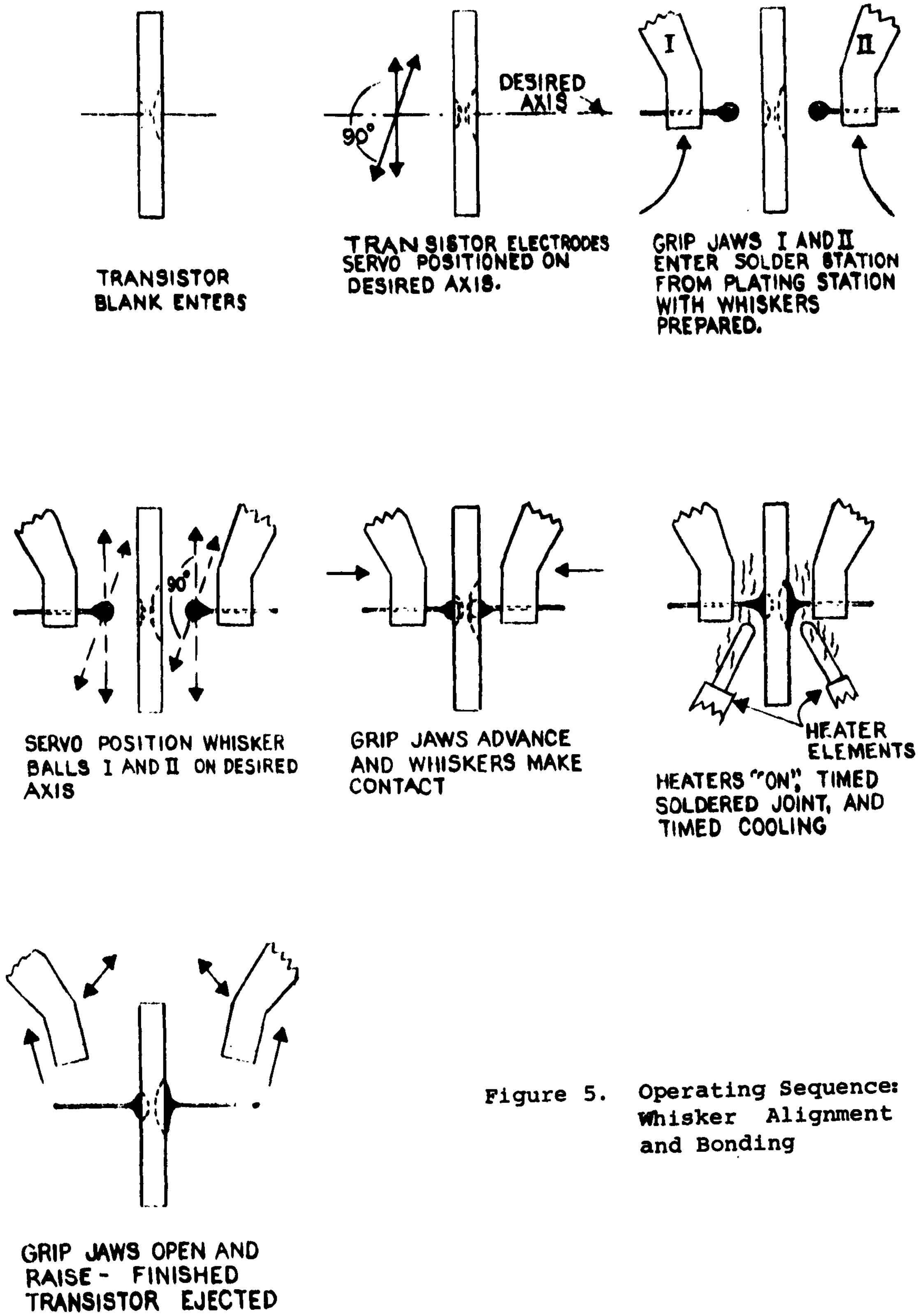

Figure 5. Operating Sequence: Whisker Alignment and Bonding

pair of whiskers has been completed, the machine comes to a stop at the 280° position of main cam rotation. Removal of the carrier with the completed transistor and insertion of a new carrier actuates the transistor electrode positioning servo. The servo accurately positions the transistor blank on a predetermined axis. Positioning information is obtained by an optics system focused on the emitter electrode. The information is amplified and controls the power to the servo motors which drive the fixture in which the transistor carrier is located. Servo positioning of the transistor electrode requires approximately 1.0 second (positioning time is adjustable from 0.5 to 3.0 seconds). Positioning accuracy with respect to the predetermined axis is $\pm 0.0001''$. Misalignment may be caused by a dirty electrode area, causing light reflections that result in erroneous positioning information to the servos. Maintenance of transistor cleanliness is very important. After servo positioning of the transistor electrode is completed, the main drive motor rotates the whisker attacher to the 360° position of main cam rotation at which the plating and soldering operations are initiated.

Plating Operation: (See Figure 4)

With the whisker wires held in a vertical position in the wire spool assembly, the plating tank assembly advances until the wires make contact with the indium plating solution. A contact sensing circuit interrupts the tank drive. A time delay within the sensing circuit can be adjusted to control the amount of immersion, thereby controlling the plated pellet size. Wire immersion must be reproducible within 0.0001" for consistent plating results. Temperature of the plating solution is held at 155°C with a Sim-Ply-Trol temperature controller. New plating solution should be provided at regular intervals, approximately every four hours during normal machine usage. An aspirator system over the plating tank removes the fumes which, if not removed, would condense on other assemblies and in time impair operation. The actual plating time is controlled by an adjustable timer. The plating tank current is 50 ma and current flow time is from 1.5 to 2.0 seconds. When plating of the whiskers is completed, the steps of bending and cutting are performed in the sequence illustrated in Figure 4.

Soldering Operation: (See Figure 5)

The plated whiskers, held in the grip jaws of the grip and transfer slide assembly, are servo positioned to the same axis as the transistor electrodes. Positioning information is provided by an optics system as in the case of transistor blank positioning. Accuracy of whisker positioning is $\pm 0.0001"$. After servo positioning of the whiskers to the correct axis, they are advanced until contact is made with their respective transistor electrodes. Sensing circuits with adjustable overtravel interrupt the advancing of the whiskers. The overtravel is reproducible within 0.0001". When the whiskers are advanced, a hydrogen jet is turned on to create a reducing atmosphere and slide-mounted heat coils are advanced. With the heat coils in soldering position, the heating current is turned on for approximately 2.0 seconds; the hydrogen ignites, and the created heat causes the plated indium on the whisker wires to fuse with the aluminum electrodes. A 1.0-second cooling period completes the solder cycle. At completion of the soldering cycle, the machine is driven to the 280° position of the main cam at which point all functions are reset and the whiskers are prepared for the next operating cycle.

MACHINE PERFORMANCE

The detailed results of production tests and data taken on devices produced using the machine are summarized below:

Production Step	Number Per Hour	Projected Number Per Shift
Machine Starts*	335	2680
Net Output from Machine Starts	317	2536
Net Units Encapsulated	271	2168
Net Final Test to 2N861 Specification	97	776

* Numbers given are actual starts. Theoretical machine starts based on known cycle of machine is 400 per hour or 3200 per shift.

The capability of the machine to meet the specified minimum production capacity of 600 units per 8 hour day meeting the applicable specifications, type 2N861, has been demonstrated. The final test yield to 2N861 specification is 36% of units encapsulated, and the full distribution of saleable transistors in the family covered by the applicable specification was 90%, or 1951 units/shift.

SECTION IV - CONCLUSIONS

The Semi-automatic Whisker Attacher designed and built on this contract has demonstrated the required capability of producing a minimum of 600 acceptable transistors meeting the applicable specification per 8-hour day. The design difficulties encountered, and the problems experienced during machine fabrication and debugging were not beyond the nature and quantity expected for an electro-mechanical equipment of this level of complexity.

Production experience with the prototype machine has shown the expected gain in production rate of whisker attachment by the automatic process as compared to the conventional manual technique. With the whisker attacher machine, 400 units per hour, based on starts possible on machine cycle time, could be produced, in comparison to 100 units per hour by an operator using manual attachment jigs, supported by a second operator producing the plated whiskers.

SECTION V - PUBLICATIONS AND REPORTS

No publications or reports pertaining to the work done on this contract have been issued.

SECTION VI - IDENTIFICATION OF PERSONNEL

The number of man-hours expended on this contract are shown below.

Engineers and Assistants	Man-Hours
Bremser, G.	1534
Brown, R.	172
Godshall, E.	2191
Weisel, D.	671
Wurz, A.	2183
Technicians, Model Makers, Miscellaneous Engineering and Drafting	8184